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Editorial: Reservoir Processes and Global Practices in Geologic Carbon Sequestration

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Editorial on the Research Topic

Reservoir Processes and Global Practices in Geologic Carbon Sequestration

Geologic carbon sequestration is a promising avenue for mitigating the deleterious effects of atmospheric CO_2 accumulation from human activities, while offering many co-benefits. For example, CO_2 can be used to displace hydrocarbons from subsurface conventional/unconventional reservoirs through enhanced oil and gas recovery or can be stored in saline aquifers or mineralized in basalt formations. The 2015 UNFCCC meet held in Paris had identified carbon capture, utilization, and storage (CCUS) as the major driver for attaining a net negative global CO_2 emission target, and a similar momentum was seen at the recently concluded Glasgow summit as well. With almost 27.5 teratonne (Tt) of geological CO_2 storage capacity available worldwide, it can provide a long-term solution to mitigate CO_2 and provide ample upscaling opportunities for the foreseeable future. According to IEA's findings, we need to store at least 2.3 Gt CO_2 annually till 2060 to restrict the global temperature rise to 2°C. With only 300 Mt CO_2 sequestrated till 2020, we need to scale up and diversify our efforts to discover and understand new sinks for optimized and safe disposal of CO_2.

Two viable routes for hydrocarbon recovery while safely sequestering CO_2 in geological formations have been practised. Miscible CO_2-EOR has proven to be very effective for boosting production from depleted oil fields, whereas CO_2-ECBM can aid in the production of methane from coal formations. Carbon mineralization in basalt formations has also been recognized as a futureproof and safe mitigation strategy for CO_2. While these are attractive engineering solutions, it is crucial that issues such as well-closure and field abandonment post-injection/production are carefully addressed. These are sensitive issues that underpin safe and reliable storage, and reservoirs should be continuously monitored for any leakage or instability in the reservoir.

Depending on the sink properties, the storage mechanism and applicable technologies widely vary, demanding a thorough understanding of macroscopic and microscopic properties of the target formation and fluids, as well as physical and geochemical interactions between them. Heterogeneities and temporal change in reservoir conditions prove challenging in proper characterization. Pore and fracture attributes and their interconnectivity provide critical insights for the migration of fluid and gaseous phases and their mutual interaction. Geomechanical and the petrophysical properties of the reservoir should be well-understood to optimize the production and safe disposal of CO_2 in the reservoir. Simulating injection/production dynamics incorporating

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laboratory and field studies for a reservoir model can help predict the changes in reservoir properties over a significant course of the operation and is very helpful in mitigating the hazards like induced seismicity, well-collapse, etc.

It is essential to develop underlying policies that facilitate the early adoption of carbon sequestration. For instance, the 45Q carbon sequestration tax credits offered in the United States incentivize injection into saline aquifers and EOR. Similarly, the EU Emission Trading Scheme also includes CCUS within its directives. It is also essential to understand the effectiveness of such incentives in creating appropriate market conditions. Further, there is a growing literature on the extent to which sequestration could be net-negative when considering large upstream and downstream emissions.

In this special issue, we highlight current research in various facets of CO_2 storage, ranging from zoomed-out areas like storage potential estimation to zoomed-in areas like site-screening and molecular dynamics. The issue focused on understanding the reservoir flow dynamics and optimizing storage capacity for CO_2 sequestration.

The paper titled "Revisiting geologic storage potential in unconventional formations is key to proactive decision making on CCS in India" by Singh et al. suggests that the storage potential for CO_2 in Indian coal and shale reservoirs might be much higher than previously estimated. The authors estimate that the total volume of coal deposits available as suitable sinks in India might be 7–8 times higher than the current assessment. Furthermore, their analysis shows that Indian shale reservoirs, which have not been assessed for underground CO_2 storage, may have substantial storage potential through adsorption. They revisit the assumptions taken for current storage estimations and demonstrate that CO_2 storage capacity of deep coal seams and shale formations could increase significantly. They provide a comprehensive framework for revising these estimates and offer detailed recommendations based on best practices for storage in unconventional reservoirs. Moreover, they make a context-specific case for storage in these unconventional reservoirs in Indian basins due to their proximity to large point sources of CO_2 through proof-of-concept source-sink mapping, especially in the western part of the country.

It is also essential to understand the primary controls when CO_2 is injected into rocks to screen suitable reservoirs. In the paper titled, "Sensitivity analysis of geomechanical constraints in CO_2 storage to screen potential sites in deep saline aquifers," Verma et al. have carried out a parametric analysis of key geomechanical rock properties such as porosity, permeability, permeability anisotropy, and compressibility along with formation water salinity and injection rate to identify significant constraints in CO_2 storage. Usually, the storage capacity of a reservoir is limited by the increase in pore pressure in the short term and by the volumetric extents of the reservoir in the long term. The selected properties affect the pore pressure and the migration of CO_2 in the reservoir. In the case of pore pressure increase, the authors found that the most sensitive property was permeability, closely followed by injection rate. Permeability and porosity affected CO_2 migration the most, with a positive and negative trend, respectively. Based on the results, the authors recommend different criteria for screening potential sites for CO_2 storage. Permeability and injection rate become the major deciding factors for reservoirs where pore pressure is closer to the minimum principal stress. In formations where reservoir capacity is constrained either through the limited dimensions of the reservoir or the presence of leakage pathways, porosity plays a dominant role in restricting CO_2 migration and increasing confidence in storage. Thus, we need to pay attention to both pore pressure build-up and CO_2 migration as storage constraints while screening potential reservoirs and planning storage projects.

Carbon storage in mafic rocks is another promising strategy for permanently isolating CO_2, while expanding geographic opportunities for CCUS. This approach is predicated on rapid mineralization reactions that convert dissolved CO_2 into carbonate minerals. Sendula et al. In their paper titled "Synthetic fluid inclusions XXIV. *in situ* monitoring of the carbonation of olivine under conditions relevant to carbon capture and storage using synthetic fluid inclusion micro-reactors: determination of reaction rates" analyze the feasibility of commercial injection of CO_2 in mafic and ultramafic rocks for permanent carbon mineralization. They measured the real-time reaction rates of CO_2 bearing aqueous solutions with olivine and quantified the amount of CO_2 mineralized at different temperature and pressure conditions. They observed that magnesite formation was significantly faster at higher temperatures. Moreover, reaction rates using seawater-like fluids were considerably higher than solutions with low salinity. Their results indicate that injection of CO_2 in submarine environments (where pores are filled with high salinity water) might offer faster permanent storage compared to onshore basalts, where basalt formations are frequently characterized by low salinity fluids. They also conclude that CO_2 mineralization in the presence of seawater-like solution is sufficiently fast enough to ensure long-term storage of CO_2 in commercial storage projects in offshore olivine-rich basalts.

Along with the capture and storage of CO_2, storing excess renewable natural gas is also essential to meet our energy demands while combating climate change. In their paper titled "The role of surface hydrophobicity on the structure and dynamics of CO_2 and CH_4 confined in silica nanopores" by Mohammed et al., they have attempted to understand the molecular level interactions of CO_2 and CH_4 in silica nanopores to study the behavior of these gases in subsurface environments. They investigated the extent of adsorption of CO_2 and CH_4 on OH- and CH_3-terminated silica pores with diameters ranging from 2–10 nm. They observed that CO_2 adsorbs to a higher extent compared to CH_4 molecules. They also noticed that the diffusivities of both gases were positively correlated with the pore diameter. These results help in developing an understanding of the organization and transport behavior of these gases in subsurface geologic formations. Such studies also provide an important starting point for storage of other gases such as hydrogen and compressed air for energy storage.

AUTHOR CONTRIBUTIONS

VV: original draft. SPP, RK, RMP, and AKS: review and editing. All authors contributed to the article and approved the submitted version.

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